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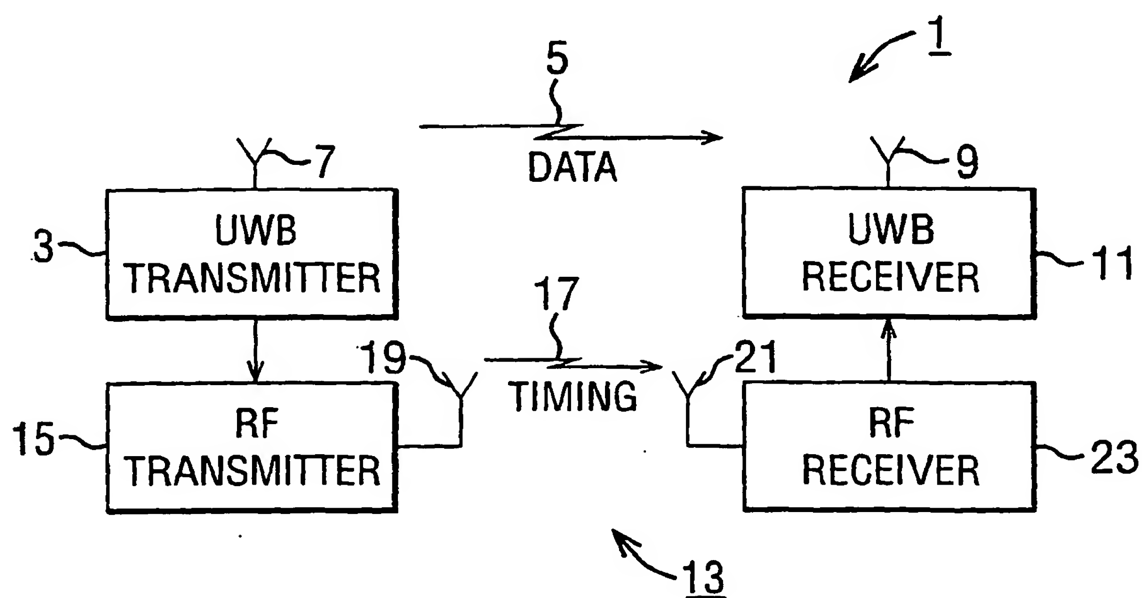

(57) Abstract: An ultra-wideband (UWB) communication system is described in which an auxiliary narrowband communication link is provided on which timing information is transmitted for use in synchronising the UWB receiver to the UWB transmitter. The auxiliary narrowband communications link may be a purpose built system transmitting specifically between the UWB devices, or it may be an externally generated or broadcast system that can be received at the UWB devices. The auxiliary communication link may be radio, acoustic, optical or wired.

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TIMING AID FOR ULTRA-WIDEBAND SYSTEM

The present invention relates to a timing aid for use in ultra-wideband transmission systems.

Within the radio frequency industry ultra-wideband is an emerging new technology for designing radio links. The core concept is to radiate an extremely broadband signal, compared to traditional systems operating on a similar centre frequency. For a signal to be defined as ultra-wideband, it must have a fractional bandwidth of at least 25% relative to the centre frequency. Most existing ultra-wideband systems are currently operating with low gigahertz (GHz) centre frequencies, with bandwidths from 500 MHz to several GHz. The advantage of ultra-wideband transmission systems is that provided the information bandwidth which is transmitted is significantly lower than the actual transmitted bandwidth, very high processing gains are possible in the receiver. This allows successful data communications between a transmitter and receiver at very low transmitted power levels.

Existing ultra-wideband systems use time-modulated pulse trains to transmit the data. Typically, these ultra-wideband systems use pulses with a pulse width between 0.2 and 1.5 nanoseconds (ns) and with pulse-to-pulse intervals of between 25 and 1000 ns. The pulse-to-pulse interval is varied on a pulse-by-pulse basis in accordance with the information signal to be transmitted

and a channel code. The pulses are then applied directly to the transmission antenna, creating the ultra-wideband transmission.

The signal received at the receiver antenna is then converted into a base band output signal through the use of a front end cross-correlator. In order to do this successfully, the position in time of the received pulse train must be known very accurately so that the cross-correlator can be synchronised with the incoming signal. The process of synchronisation of the receiver to the transmitter is referred to as the acquisition of the signal by the receiver.

One of the main problems with current time-modulated ultra-wideband signals is that the acquisition time at the start of the transmission may be of the order of a second and consequently is a considerable overhead.

The present invention addresses this acquisition problem and provides an alternative technique which can be used to reduce the acquisition time in such ultra-wideband transmission systems.

According to one aspect, the present invention provides an ultra-wideband communication system comprising an ultra-wideband transmitter and receiver and means for synchronising the timing of operation of the transmitter and the receiver. The synchronising means preferably includes a transmitter for transmitting timing

information to at least one of the ultra-wideband transmitter and receiver for synchronising its timing of operation. The timing information can be transmitted as a narrowband signal either as one or more single tones or as narrowband data. The timing information may be carried by a mechanical or an electromagnetic wave.

The present invention also provides an ultra-wideband transmitter and an ultra-wideband receiver adapted to receive this transmitted timing information and to synchronise their timing of operation in dependence upon the received timing information.

Various other features and advantages of the present invention will become clear from the following description of exemplary embodiments which are described with reference to the following drawings in which:

Figure 1 is a schematic block diagram showing an ultra-wideband transmission and reception system together with a narrowband auxiliary channel used to provide timing information for synchronising the transmitter and the receiver of the ultra-wideband system;

Figure 2 is a schematic block diagram illustrating the main components of the ultra-wideband transmitter shown in Figure 1;

Figure 3a is a timing diagram illustrating a sequence of 1 nanosecond pulses repeating every 1 microsecond

transmitted to the receiver in the ultra-wideband system shown in Figure 1;

Figure 3b illustrates the way in which the position of the 1 nanosecond pulses shown in Figure 3a are modulated to carry data from the ultra-wideband transmitter to the ultra-wideband receiver shown in Figure 1;

Figure 4 is a timing diagram illustrating the frames and timeslots in which the pulses shown in Figure 3 are transmitted in the ultra-wideband transmitter and receiver system shown in Figure 1;

Figure 5 is a schematic block diagram illustrating the main components of the ultra-wideband receiver shown in Figure 1;

Figure 6 is a schematic block diagram illustrating the main components of a receiver according to a second embodiment;

Figure 7 is a schematic block diagram illustrating the main components of a ultra-wideband receiver according to a third embodiment;

Figure 8 is a schematic block diagram illustrating the main components of an ultra-wideband transmission and reception system in which timing information is transmitted between the transmitter and receiver using the mains electricity distribution network;

Figure 9 is a schematic block diagram illustrating an ultra-wideband transmission system in which timing information is transmitted over an auxiliary acoustic data channel; and

Figure 10 is a schematic block diagram of an ultra-wideband transmission system in which timing information is transmitted to the communicating parties by a third party timing controller.

Overview

Figure 1 is a block diagram illustrating an ultra-wideband (UWB) transmitter and receiver system 1 having a UWB transmitter 3 which transmits ultra-wideband data (represented by the data arrow 5) from the transmitting antenna 7 to the receiving antenna 9 of a UWB receiver 11. As shown in Figure 1, the UWB system also includes a narrowband auxiliary data channel 13 having an RF transmitter 15 which is operable to transmit narrowband timing data (represented by the timing arrow 17) from a transmitting antenna 19 to the receiving antenna 21 of an RF receiver 23.

In this embodiment, the UWB transmitter 3 acts as the reference clock for the UWB system 1. Timing information from the UWB transmitter 3 is therefore passed to the RF transmitter 15 which operates to transmit this timing information to the RF receiver 23. The RF receiver 23 then passes this timing information to the UWB receiver 11 to aid in the synchronisation of the UWB receiver 11

to the UWB transmitter 3. In particular, the timing information is used to aid in the acquisition of the transmitted UWB signal by the UWB receiver 11. Once acquisition has been achieved, the UWB receiver can then track the transmitted UWB signal 5 using conventional tracking techniques.

The above description gives a general overview of the principle underlying the present invention. In order to illustrate the problems associated with ultra-wideband systems, a description will now be given in more detail of a UWB transmitter and receiver system and illustrating the type of timing information which may be transmitted for aiding the acquisition process.

UWB Transmitter

Figure 2 is a block diagram illustrating the main components of the UWB transmitter 3 shown in Figure 1. UWB transmitter 3 generates an output train of pulses for each bit of information to be transmitted. These pulse trains are generated by the pulse generator 31. Figure 3a is a timing diagram showing the unmodulated pulse train generated by the pulse generator 31 in this embodiment. As shown, the pulse generator 31 is operable to generate monocycle pulses 33-1 to 33-3 which have a duration of approximately 0.5 nanoseconds (ns) and a pulse repetition rate of the order of 0.1 microseconds (μs). In order to modulate data onto the pulse train, the exact timing of each pulse is modulated in dependence upon the data to be transmitted. In particular, each

pulse is either advanced or delayed relative to a nominal pulse position. This is illustrated in Figure 3b which shows a previously transmitted pulse 33-4 followed by a sequence of three pulses 33-5 to 33-7 illustrating the possible timings of the next pulse to be transmitted. Pulse 33-5 represents an advanced version of the pulse. Pulse 33-6 represents the unmodulated position of the pulse and pulse 33-7 represents a delayed version of the pulse. As illustrated in Figure 3b, in this embodiment the pulse is either advanced or delayed by one-quarter of the pulse period relative to the unmodulated pulse 33-6. In this embodiment, if a binary 1 is to be transmitted then the advanced pulse 33-5 is transmitted whereas if a binary 0 is to be transmitted the delayed pulse 33-7 is transmitted. Returning to Figure 2, the data delay unit 35 is operable to output the appropriate advance or delay time in dependence upon the current data bit to be transmitted from "DATA IN".

In order to smooth the transmitted frequency response of the transmitted pulses and in order to provide channelisation, the transmitted pulses are also coded with a pseudo random (PR) code which is generated by the code generator 37. In particular, each 0.1 microsecond pulse interval is divided into a number of discrete time slots and the code generator is used to pseudo-randomly choose the slot in which the pulse will be transmitted. This is illustrated in Figure 4. In particular, Figure 4 shows the sequence of 0.1 microsecond time frames 41 corresponding to the pulse repetition rate of the

unmodulated, un-channelised pulse generator 31. As shown, each time frame 41 is divided into a plurality of time slots 43 and within a selected one of these slots 43-S (selected from the PR code) the pulse 33 for the current time frame 41 is transmitted.

As those skilled in the art of telecommunications will appreciate, PR codes are binary codes which appear to be completely random in nature, but which are in fact deterministic, i.e. they can be reproduced. In particular, these codes are generated by exclusive OR feedback from synchronously clocked registers. By continually clocking the registers, the PR code is cyclically reproduced. The number of registers, the registers used in the feedback path and the initialisation state of the registers determines the length of the code and the specific code produced. In this embodiment, the code generator 37 has seven registers and generates a repeating PR code having 127 bits (which will hereinafter be referred to as chips using the standard nomenclature in the art to distinguish the bits of the PR code from the bits of the data signal to be transmitted) in a stream with no sequence of more than 7 chips repeated in the 127 chips. Such a PR code is conventionally referred to as a 7-bit code after the number of registers used to generate it. In this embodiment, the code generator 37 generates a new chip of the code once every frame 41 and therefore, the PR code generated by the code generator 37 will repeat every 12.7 microseconds.

In this embodiment, each of the time frames 41 is divided into 127 time slots 43, one for each of the 127 unique consecutive 7-bit sequences appearing in the code generated by the code generator 37. The relationship between each 7-bit sequence and the corresponding time delay for the appropriate time slot 43 is defined by the entries in the code delay lookup table 45. As shown in Figure 2, the code sequence generated by the code generator 37 is sequentially passed through a bank of seven serially connected registers 47 with the output of the seven registers being used to address the code delay lookup table 45. Table 1 below illustrates the form of the code delay lookup table 45 used in this embodiment.

Table 1

PR Code Sequence	Time Delay
0000001	t_1
0000010	t_2
0000011	t_3
0000100	t_4
0000101	t_5
0000110	t_6
0000111	t_7
0001000	t_8
⋮	⋮
1111111	t_{127}

The output from the code delay unit 45 is a time delay (t_{slot}) defined from the beginning of the time frame 41 which is added to the time delay or time advance output by the data delay unit 35 in the adder 47. The combined time delay is then used to programme a programmable time delay unit 49 which controls the generation of the pulses by the pulse generator 31. In particular, the programmable time delay unit 49 receives a clock signal from the clock oscillator 51 (which operates, in this embodiment, at 10 MHz corresponding to the frequency of the transmitted time frames 41) and delays the application of an appropriate actuation signal to the pulse generator 31 by the time delay defined by the time delay signal it receives from the adder 47.

As shown in Figure 2, the clock signal output by the clock oscillator 51 is also used to clock the code generator 37, the registers 47 and the data delay unit 35. In this embodiment, the code generator 37 generates the next chip in the sequence, and one chip is shifted through the registers 47, upon the rising edge of the clock signal. In contrast, the data delay unit 35 is only operable to read in the next data bit to be transmitted every one hundredth clock period (corresponding to a data rate of 100 kb/s). In this way, in this embodiment one-hundred UWB pulses 33 are transmitted from the UWB transmitter 3 to the UWB receiver 11 for each data bit to be transmitted. As those skilled in the art will appreciate, this provides processing gain in the receiver.

As mentioned above, in this embodiment, the UWB transmitter 3 acts as the timing reference for the UWB transmitter and receiver system 1. In this embodiment, timing information on the frequency and phase of the clock generated by the clock oscillator 51 is passed to the RF transmitter 15 which transmits this timing information to the RF receiver 23 via the transmitting antenna 19. In this embodiment, the signal passed to the RF transmitter is the 10 MHz clock signal itself which is transmitted directly as a corresponding RF tone at 10 MHz to the RF receiver 23. The transmitted tone 53 is shown in Figure 4 which illustrates that the positive going zero crossings of the tone correspond to the start of each time frame 41. The receiver can therefore use this tone to synchronise the operation of its internal clock.

UWB Receiver

Figure 5 is a block diagram illustrating the main components of the UWB receiver 11 used in this embodiment. As shown, the signal received at the receive antenna 9 is input to a correlator 61 where the received pulses are correlated with a corresponding locally generated set of pulses generated by the pulse generator 63. As shown in Figure 5, the correlator 61 comprises a multiplier 65, an integrator 67 and a sample and hold circuit 69. In this embodiment, the integration period corresponds to half the bit rate of the received data, i.e. 5 microseconds. The correlation outputs from the sample and hold circuit 69 are then input to a signal

processing unit 71 which processes the correlation values to recover the transmitted data which it outputs as "DATA OUT".

In order that the signal processing unit 71 can recover the transmitted data, the correlator 61 must be synchronised with the incoming UWB pulses. This requires a code generator 73 which can generate the same PR code that was generated by the code generator 37 in the UWB transmitter 3. As before, the code generated by the code generator 73 is used to address a code delay lookup table 75 (which again is the same as the code delay lookup table 45 used in the UWB transmitter 3) via the seven registers (not shown). The code generator 73 and the code delay lookup table 75 operate to identify the appropriate code delay to be output for the current pulse. In addition to this delay, there is also the time delay or advance introduced by the data delay unit 35 in the transmitter 3. To account for this delay, the signal processing unit 71 considers both possibilities.

In particular, initially the signal processing unit 71 outputs a delay corresponding to a quarter of a pulse delay which is added to the delay generated by the code delay unit 75 in the adder 77 (which corresponds to the situation when a binary zero is transmitted). The total delay is then used to programme the programmable time delay unit 79 in the same way as the corresponding programmable time delay unit 49 in the transmitter 3 was programmed. The signal processing unit 71 outputs this

same delay value for the entire five microsecond integration period of the integrator 67 and stores the accumulated correlation result. At the end of this integration period, the signal processing unit 71 then changes the time delay it outputs to the adder 77 to correspond to a timing advance of quarter of the pulse (which corresponds to the situation when a binary one is transmitted) and again this time delay is applied to the adder 77 for the next five microsecond integration period of the integrator 67. At the end of that integration period, the correlation result is output from the sample and hold circuit 69 to the signal processing unit 71 which compares the result with the result from the previous integration period. If the correlation result of the first integration period is greater, then this means that the data transmitted was a binary zero, whereas if the correlation result from the second integration period is greater, then this means that data transmitted was a binary one.

As those skilled in the art will appreciate, the UWB receiver 11 can only recover the transmitted data when it is synchronised to the UWB transmitter 3. This involves ensuring that the clock signal of the receiver 11 generated by the clock oscillator 81 is matched in frequency and phase to the clock signal generated by the clock oscillator 51 in the transmitter 3. Full synchronisation also requires the synchronisation of the code generators 37 and 73, so that they generate the same code at the same time. However, in this embodiment, only

information on the clock signal generated by the transmitter clock oscillator 51 is transmitted from the RF transmitter 15 to the RF receiver 23. As a result, only the clock oscillator 81 can be easily synchronised with the clock oscillator 51 in the transmitter 3 and conventional acquisition techniques must be used in order to synchronise the code generator 73 in the receiver 11 with the code generator 37 in the transmitter 3. The way in which these conventional acquisition systems work is well known to those skilled in the art and will not be described further here.

In an alternative embodiment, in addition to or instead of timing information on the clock frequency of the clock oscillator 51, timing information concerning the code sequence generated by the code generator 37 may be also be transmitted to the UWB receiver 11 via the RF transmitter 15 and the RF receiver 23. In this case, the timing information on the code may define each time the code generator 37 starts the code. This could be transmitted, for example, by an appropriately phased tone at a frequency of approximately 78.7 kHz (representing the repeat frequency of the code used in this embodiment). Figure 6 is a schematic block diagram illustrating the main components of a receiver which would be used in an embodiment where both clock frequency and code repetition frequency timing information is transmitted to the UWB receiver 11. As shown, the only difference is in the provision of the additional control line 85 from the RF receiver 23 going to the code

generator 73 in order to synchronise the code generator 73 with the code generator 37 in the UWB transmitter 3.

In the above two embodiments, the clock frequency of the local clocks corresponded to the repetition rate of the time frames 41. As those skilled in the art will appreciate, this may not be the case in all embodiments. For example, a digitally programmable time delay unit 79 may be used in which the timing of the individual slots 43 within the time frame 41 is controlled by the local clock. In this case, with the above chip rate the clock would have to operate at 1.27 GHz. In such an embodiment, in addition to or instead of transmitting timing information concerning the clock signal generated by the clock oscillator 51, timing information defining the start of each of the time frames 41 may also be transmitted. This timing information would be used to synchronise the operation of the programmable time delay unit 79 used in the receiver 11. Figure 7 is a schematic block diagram illustrating the main components of a receiver 11 which received all three types of timing information, i.e. timing information on the clock frequency, timing information on the code generator and timing information on the start times of the transmitted time frames 41. As shown in Figure 7, the only difference between this embodiment and the embodiment shown in Figure 6 is the addition of the control line 87 on which the timing information concerning the start times of the transmitted time frames 41 are passed to the programmable time delay unit 79.

In the embodiments described above, the timing information was transmitted on an auxiliary narrowband RF frequency channel. As those skilled in the art will appreciate, it is not essential to transmit the auxiliary narrowband information on an RF communications channel. Figure 8 illustrates an alternative system in which the timing information is transmitted over the mains electricity distribution network 91 between a mains outlet 93 located at the transmitter end and a mains outlet 95 located at the receiving end of the UWB communications link. This embodiment is particularly useful for indoor applications where such cable infra-structure already exists and fewer regulatory hurdles such as radio licensing need be overcome

Figure 9 illustrates yet another alternative auxiliary communication link in which the timing information is transmitted over an acoustic auxiliary data channel. In this case, the timing information is transmitted by an acoustic transmitter 101 via a loudspeaker 103 which are located at the transmitter end and which are received by a microphone 105 and an acoustic receiver 107 located at the UWB receiver end 11. Further, in the embodiment illustrated in Figure 9, a duplex communication link is provided between the two UWB transceivers 111 and 113. In this case, each transceiver will include the transmitter and receiver circuitry discussed above.

In the above embodiments, one end of the communication link was used as the timing reference for the other end.

As those skilled in the art will appreciate, this is not essential. A separate unit or third party timing reference may be provided which transmits timing reference signals to both ends of the communication link. Such an embodiment is illustrated in Figure 10 in which the timing information is transmitted on an RF link between an RF transmitter 15 and two RF receivers 23-1 and 23-2 located respectively at each end of the UWB communication link. As shown in Figure 10, the timing information is provided by the timing reference unit 115.

Modifications and Alternatives

A number of embodiments have been described above which illustrate the principles underlying the present invention. Whilst these embodiments have been described in detail, it will be apparent to those skilled in the art that many modifications can be made thereto. A number of these modifications will now be described for illustration.

In the above embodiments, the timing information was transmitted as one or more frequency tones, with the frequency and phase of the transmitted tone corresponding to the appropriate clock frequency. As those skilled in the art will appreciate, a lower or higher frequency tone may be transmitted provided there is appropriate multiplication or division circuitry in the corresponding receiver so that the appropriate timing signal can be re-generated from the transmitted tone. For example, in the above embodiment the clock frequency was 10 MHz. This

could be transmitted as a 1 MHz tone provided the receiver knows in advance that the received frequency must be multiplied ten times to regenerate the clock signal. Such an embodiment would be advantageous in the system described above in which the timing information is transmitted over the mains electricity distribution network since the nominal 50 Hz signal can be used as the timing information which synchronises both the transmitter and the receiver through appropriate frequency multipliers located therein.

In the embodiments described above, the timing information was transmitted as one or more frequency tones. As those skilled in the art will appreciate, instead of transmitting tones, the timing information may be encoded into data which may then be transmitted using conventional narrowband data communication techniques.

In the embodiments illustrated above, the timing information signals were transmitted over an RF communications link, an acoustic communications link or over the mains electricity distribution network. As those skilled in the art will appreciate, other options are possible. For example, the timing information may be transmitted optically or over a dedicated electrically conductive link. In general terms, the timing information may be transmitted over any communications link whether carried by mechanical waves (e.g. sound) or electromagnetic waves (e.g. light, radio, induction etc).

In the above embodiments, a pseudo-random code was used to randomly choose a time slot within a current frame in which to transmit the pulse. As those skilled in the art will appreciate, it is not essential to use such a pseudo-random code. Any deterministic code sequence may be used to select the slot in which the pulse will be transmitted, provided the same code can be generated at both the transmitter and the receiver. Further, if a pseudo-random code is being used, it is not essential to pass the code through a series of shift registers in order to address the code delay look-up table.

In the above embodiments, a particular way of demodulating the received pulses has been described. As those skilled in the art will appreciate, there are various other ways to carry out the demodulation. For example, the received pulses may be fed into a quadrature phase detector together with the locally generated pulses. This provides a similar function to the early/late correlator pair and is also suitable to detect pulse phase modulation or time and phase modulated pulses. The output from the quadrature phase detector would include an phase (I) and a quadrature phase (Q) components. These would then be input to a respective correlator which acts as a matched filter to detect the transmitted data. The output from the quadrature phase detector will also provide information useful for maintaining the synchronisation of the receiver to the transmitter.

In the above embodiments, the ultra-wideband signal that was transmitted between the transmitter and receiver was generated by pulses having a short pulse width. As those skilled in the art will appreciate, there are other techniques for generating ultra-wideband signals. For example, it is possible to use direct sequence spread spectrum techniques using a long PR code sequence to achieve the desired UWB signal. As those skilled in the art will appreciate, such systems will also suffer from difficulties in acquisition because of the very short chip period involved and will also benefit from the techniques discussed above.

In the embodiments described above, each time frame was divided into 127 slots which corresponded to the number of unique 7-chip sequences that are generated by the PR code generator. This means that each slot will be addressed once every 12.7 microseconds. However, as those skilled in the art will appreciate, this is not essential. The number of slots in each time frame may be less than the number of unique sequences in the PR code sequence. In this case, each slot may be addressed by more than one code sequence. This will not make any difference on the operation of the system provided the code delay lookup table used in the transmitter is identical to the code delay lookup table used in the receiver. Depending on the number of slots used in such an embodiment, less than 7 chips may be required to address the code delay lookup table. Further, any length of PR code may be used, it does not have to be a 7-chip

PR code. However, as those skilled in the art will appreciate, the larger the PR code, the more frequency smoothing there is and the more time slots can be defined within each time frame.

As mentioned above, one of the advantages of using the PR code is that it provides channelisation (in addition to frequency smoothing). This is because different codes may be assigned to different receivers and the transmitter may then be arranged to transmit at the same time UWB signals to the different receivers using the different codes. In effect, the transmitter will transmit the appropriate UWB signals in different time slots for the different receivers. Occasionally, however, there will be a conflict between the different codes (in that they will want to transmit during the same time slot). However, this is not a severe problem since each data bit is encoded with a relatively large number of consecutive pulses and the effect of collisions on a few of the pulses will be negligible. This channelisation also allows other transmitters and receivers to operate in the vicinity without there being any interference.

In the above embodiments, each data bit that was transmitted from the transmitter to the receiver was transmitted as 100 pulses and the receiver performed two correlations using 50 of those pulses for each correlation, from which it determined if the transmitted data was a 1 or a 0. As those skilled in the art will

appreciate, instead of time division multiplexing the operation of the single correlator, the receiver may have two correlators connected in parallel, with each correlator correlating the incoming pulses with an early and a late version of the locally generated pulses, from which the state of the transmitted data can be determined. Such a parallel configuration of correlators also allows more averaging to take place or allows a doubling of the data rate for the same amount of averaging.

In the above embodiments, pulses having a duration of approximately 0.5 nanoseconds were used with a repetition frequency of approximately 0.1 microsecond. As those skilled in the art will appreciate, this is not essential. Monocycle pulses typically having a duration of 1 picosecond to 10 nanoseconds may be used. Further, the pulse repetition rate or the frame rate may typically be between one every 1 nanosecond to 1 millisecond.

In the above embodiments, the data to be transmitted was used to modulate the timing of the transmitted pulse about a quarter of the pulse duration. As an alternative, the phase, amplitude or the number of the transmitted pulses may be modulated depending on the data to be transmitted. For example, to transmit a binary 1, each pulse may be transmitted without delay and to transmit a binary 0 the phase of each pulse may be changed by 180°. The correlator and the digital signal processor in the receiver can detect this change and

therefore can detect whether or not a binary 0 or a binary 1 was transmitted.

In the above embodiments, the timing information may be transmitted continuously over the auxiliary communications link. However, since it is only needed during initial acquisition and if there is a loss of synchronisation between the transmitter and the receiver, the timing information need only be transmitted intermittently or at the beginning of each transmission.

In the above embodiments, the receiver was synchronised to the transmitter by the receiver receiving timing information that was either transmitted from the transmitter or that was transmitted from a central timing controller. As those skilled in the art will appreciate, it is possible to synchronise the operation of the transmitter to the operation of the receiver instead. In this case, the receiver would transmit data identifying the timing information associated with its internal clocks to the transmitter which would then synchronise its internal clocks to those of the receiver.

CLAIMS:

1. An ultra-wideband communication system comprising:

an ultra-wideband transmitter operable to transmit ultra-wideband signals;

an ultra-wideband receiver operable to receive the transmitted ultra-wideband signals; and

means for synchronising the timing of operation of at least one of the ultra-wideband transmitter and the ultra-wideband receiver;

characterised in that said synchronising means comprises:

(i) means for transmitting timing information relating to a desired timing of operation of said at least one of said ultra-wideband transmitter and said ultra-wideband receiver;

(ii) means associated with said at least one of said ultra-wideband transmitter and said ultra-wideband receiver, for receiving said transmitted timing information; and

(iii) means associated with said at least one of said ultra-wideband transmitter and ultra-wideband receiver, for synchronising the timing of operation of said at least one of said ultra-wideband transmitter and ultra-wideband receiver in accordance with the received timing information.

2. A system according to claim 1, wherein said transmitter comprises means for receiving data to be transmitted; and a modulator for modulating the data onto

an ultra-wideband carrier signal; wherein said receiver comprises a demodulator for demodulating the received modulated ultra-wideband signal to recover the data signal; and wherein said synchronising means is operable to synchronise the timing of operation of at least one of the modulator and the demodulator.

3. A system according to claim 1 or 2, wherein said synchronising means is operable to synchronise the timing of a clock used in said at least one of said ultra-wideband transmitter and ultra-wideband receiver.

4. An apparatus according to any preceding claim, wherein said ultra-wideband transmitter is operable to transmit said ultra-wideband signals during predetermined time frames and wherein said synchronising means is operable to synchronise the timing of operation of said at least one of said ultra-wideband transmitter and ultra-wideband receiver in respect of the timings of said predetermined time frames.

5. An apparatus according to any preceding claim, wherein said ultra-wideband transmitter comprises a code generator for generating a pseudo-random code and means for generating the ultra-wideband signals to be transmitted using the generated PN code, wherein said ultra-wideband receiver comprises a code generator for generating a pseudo-random code which corresponds to the pseudo-random code generated by the code generator of said transmitter and wherein said synchronising means is

operable to synchronise the timing of operation of said at least one of said ultra-wideband transmitter and ultra-wideband receiver by controlling start times of the generation of said code by the corresponding code generator.

6. A system according to any preceding claim, wherein said transmitting means of said synchronising means is operable to transmit said timing information as a radio signal.

7. An apparatus according to any of claims 1 to 5, wherein said transmitting means of said synchronising means is operable to transmit said timing information as an acoustic signal.

8. A system according to any of claims 1 to 5, wherein said transmitting means of said synchronising means is operable to transmit said timing information as an optical signal.

9. A system according to any of claims 1 to 5, wherein said transmitting means of said synchronising means is operable to transmit said timing information over an electrically conductive link.

10. A system according to claim 9, wherein said wire link forms part of the electricity mains or any other electrically conducting infrastructure.

11. An apparatus according to any preceding claim, wherein said transmitter of said synchronising means is associated with said ultra-wideband transmitter and wherein said synchronising means is operable to synchronise the timing of operation of said ultra-wideband receiver.

12. A system according to any of claims 1 to 10, wherein said transmitting means of said synchronising means is associated with said ultra-wideband receiver and wherein said synchronising means is operable to synchronise the timing of operation of said ultra-wideband transmitter.

13. A system according to any preceding claim, wherein said transmitting means of said synchronising means is associated with a central timing controller and wherein said synchronising means is operable to synchronise the timing of operation of both said ultra-wideband receiver and said ultra-wideband transmitter.

14. A system according to any preceding claim, wherein said ultra-wideband transmitter is operable to transmit pulses of electromagnetic energy and wherein said ultra-wideband receiver is operable to correlate the received pulses with locally generated pulses.

15. A system according to claim 14, wherein said ultra-wideband transmitter is operable to transmit data between said ultra-wideband transmitter and said ultra-wideband receiver by modulating the timing, phase, amplitude or

number of the pulses or any combination of these in dependence upon the data to be transmitted.

16. An apparatus according to claim 14 or 15, wherein said ultra-wideband transmitter is operable to transmit said pulse within one of a plurality of predetermined time slots and further comprising means for randomly selecting the slot in which the pulse is transmitted.

17. A system according to claim 16, wherein said means for randomly selecting said time slot comprises a pseudo-noise code generator.

18. An apparatus according to any of claims 14 to 17, wherein said ultra-wideband transmitter is operable to transmit pulses having a duration between 1 picosecond and 10 nanoseconds.

19. An apparatus according to any of claims 14 to 18, wherein said ultra-wideband transmitter is operable to transmit said pulses at a repetition rate of one every 1 nanosecond to 1 millisecond.

20. An ultra-wideband communication system comprising:

an ultra-wideband transmitter operable to transmit ultra-wideband signals;

an ultra-wideband receiver operable to receive the transmitted ultra-wideband signals; and

means for synchronising the timing of operation of the ultra-wideband receiver and the ultra-wideband

transmitter;

characterised in that said synchronising means comprises:

(i) means for transmitting narrowband timing information of the timing of operation of one of said ultra-wideband transmitter and said ultra-wideband receiver;

(ii) means associated with the other one of said ultra-wideband transmitter and ultra-wideband receiver, for receiving said narrowband timing information; and

(iii) means associated with the other one of said ultra-wideband transmitter and ultra-wideband receiver, for synchronising said other one of said ultra-wideband transmitter and ultra-wideband receiver to said one of said ultra-wideband transmitter and said ultra-wideband receiver.

21. An ultra-wideband communication system comprising:

an ultra-wideband transmitter comprising:

(i) means for receiving a data signal to be transmitted;

(ii) means for modulating the data onto an ultra-wideband carrier signal; and

(iii) means for transmitting the modulated ultra-wideband carrier signal;

an ultra-wideband receiver comprising:

(i) means for receiving the transmitted modulated ultra-wideband signal; and

(ii) means for demodulating the received modulated ultra-wideband signal to recover the data signal; and

means for synchronising the timing of operation of said ultra-wideband modulator and said ultra-wideband demodulator;

characterised in that said synchronising means comprises:

(i) means for transmitting narrowband timing information of the timing of operation of one of said ultra-wideband modulator and said ultra-wideband demodulator;

(ii) means associated with the other one of said ultra-wideband modulator and said ultra-wideband demodulator, for receiving said narrowband timing information; and

means associated with said other one of said ultra-wideband modulator and ultra-wideband demodulator, for synchronising the timing of operation of said other one of said ultra-wideband modulator and said ultra-wideband demodulator to the timing of operation of said one of said ultra-wideband modulator and said ultra-wideband demodulator.

22. An ultra-wideband transmitter comprising:

means for receiving data to be transmitted;

means for modulating the data onto an ultra-wideband carrier signal;

a first transmitter for transmitting the modulated ultra-wideband signal; and

a second transmitter for transmitting narrowband timing information defining a desired timing of operation of an ultra-wideband receiver which is operable for

receiving the transmitted modulated ultra-wideband signal.

23. An ultra-wideband transmitter according to claim 22, wherein said second transmitter is operable to transmit said timing information over an electromagnetic or an acoustic communications channel.

24. An ultra-wideband receiver comprising:

a first receiver for receiving modulated ultra-wideband signals;

a demodulator for demodulating the received modulated ultra-wideband signals; and

a second receiver for receiving narrowband timing information defining a desired timing of operation of said demodulator.

25. An ultra-wideband receiver according to claim 24, wherein said second receiver is operable to receive said narrowband timing information over an electromagnetic or an acoustic communications link.

26. An ultra-wideband receiver comprising:

a receiver for receiving modulated ultra-wideband signals;

a demodulator for demodulating the modulated ultra-wideband signals; and

a transmitter for transmitting narrowband timing information defining a desired timing of operation of the ultra-wideband transmitter which transmitted said

received modulated ultra-wideband signals.

27. An ultra-wideband receiver according to claim 26, wherein said transmitter is operable to transmit said narrowband timing information via an electromagnetic or an acoustic communications link.

28. An ultra-wideband transmitter comprising:

means for receiving data to be transmitted;

means for modulating the data onto an ultra-wideband carrier signal;

a transmitter for transmitting demodulated ultra-wideband signal; and

a receiver for receiving narrowband timing information defining a desired timing of operation of said modulating means.

29. An ultra-wideband transmitter according to claim 28, wherein said receiver is operable to receive said narrowband timing information via an electromagnetic or an acoustic communications channel.

30. An ultra-wideband communication method comprising the steps of:

transmitting ultra-wideband signals;

receiving the transmitted ultra-wideband signals; and

synchronising the timing of operation of at least one of the transmitting and receiving steps;

characterised in that said synchronising step

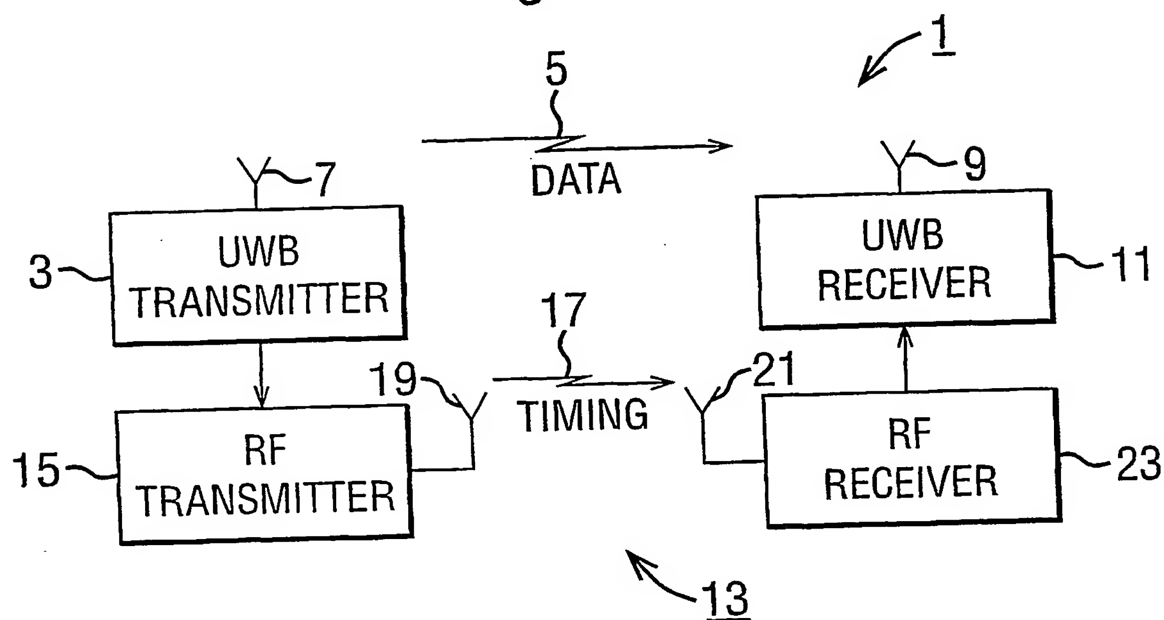
comprises the steps of:

(i) transmitting timing information defining a desired timing of operation of said at least one of said transmitting and receiving steps;

(ii) receiving said transmitted timing information; and

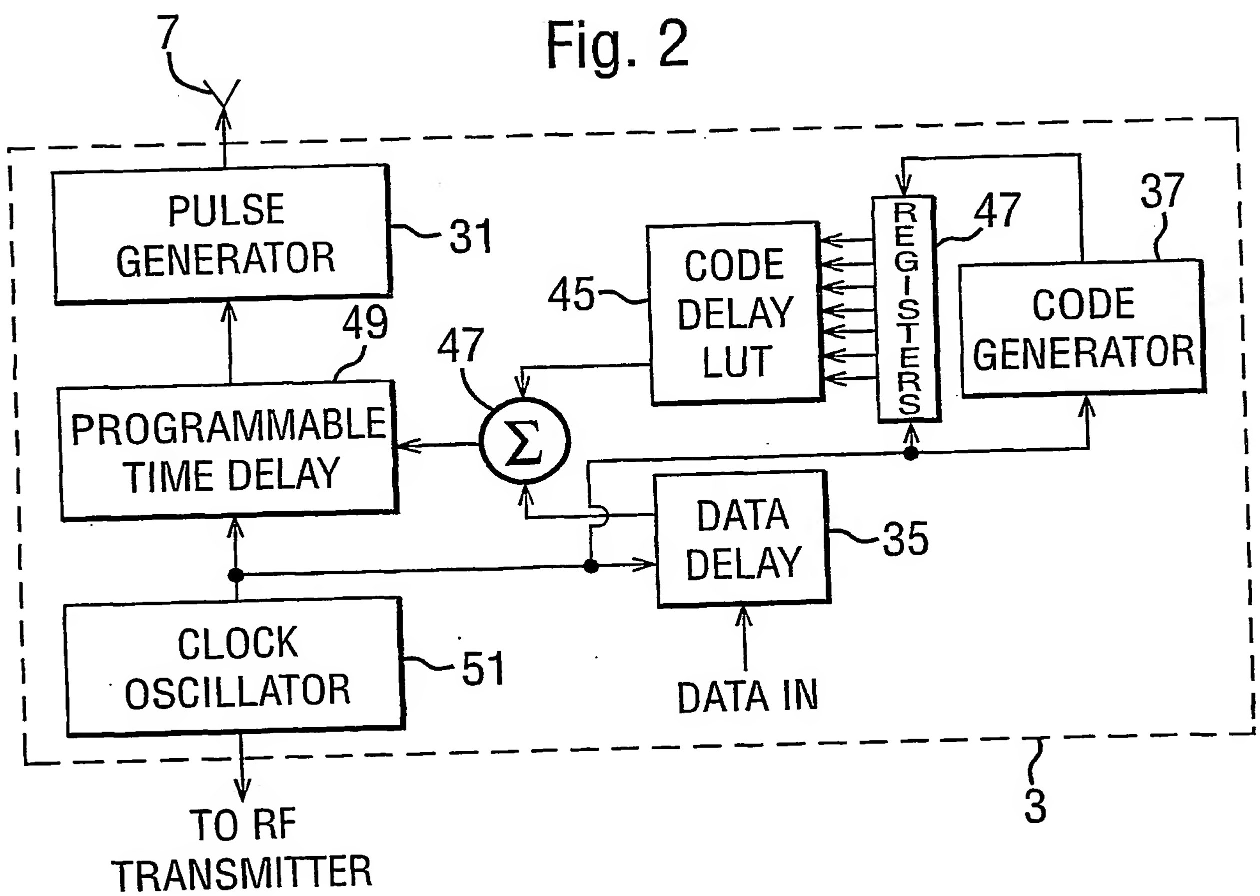
(iii) synchronising the timing of operation of said at least one of said transmitting and receiving steps in accordance with the received timing information.

Fig. 1



1
5
DATA
7
9
3
UWB TRANSMITTER
UWB RECEIVER
11
17
19
21
TIMING
15
RF TRANSMITTER
RF RECEIVER
23
13

Fig. 2



7
PULSE GENERATOR
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REGISTERS
47
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CODE DELAY LUT
CODE GENERATOR
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47
PROGRAMMABLE TIME DELAY
Σ
DATA DELAY
35
CLOCK OSCILLATOR
51
DATA IN
TO RF TRANSMITTER
3

Fig. 3a

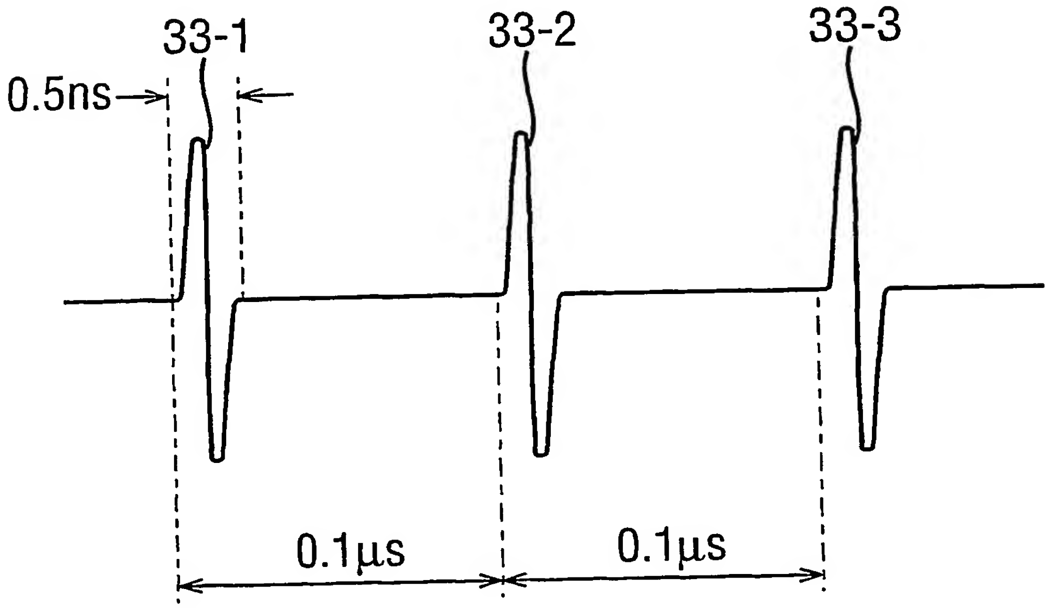


Fig. 3b

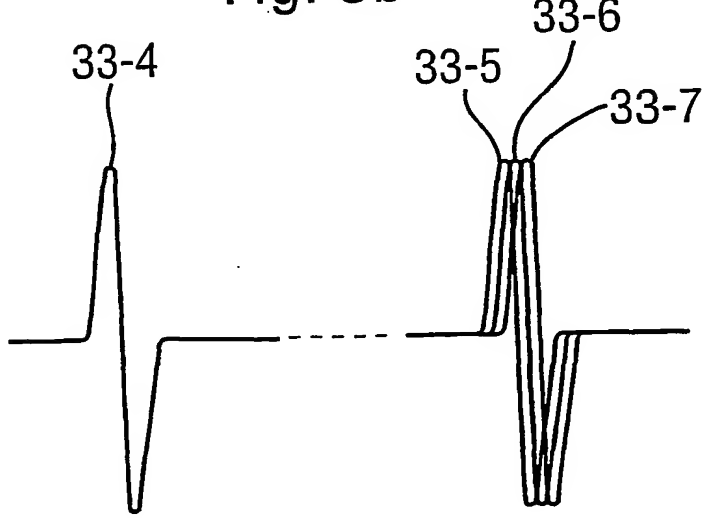
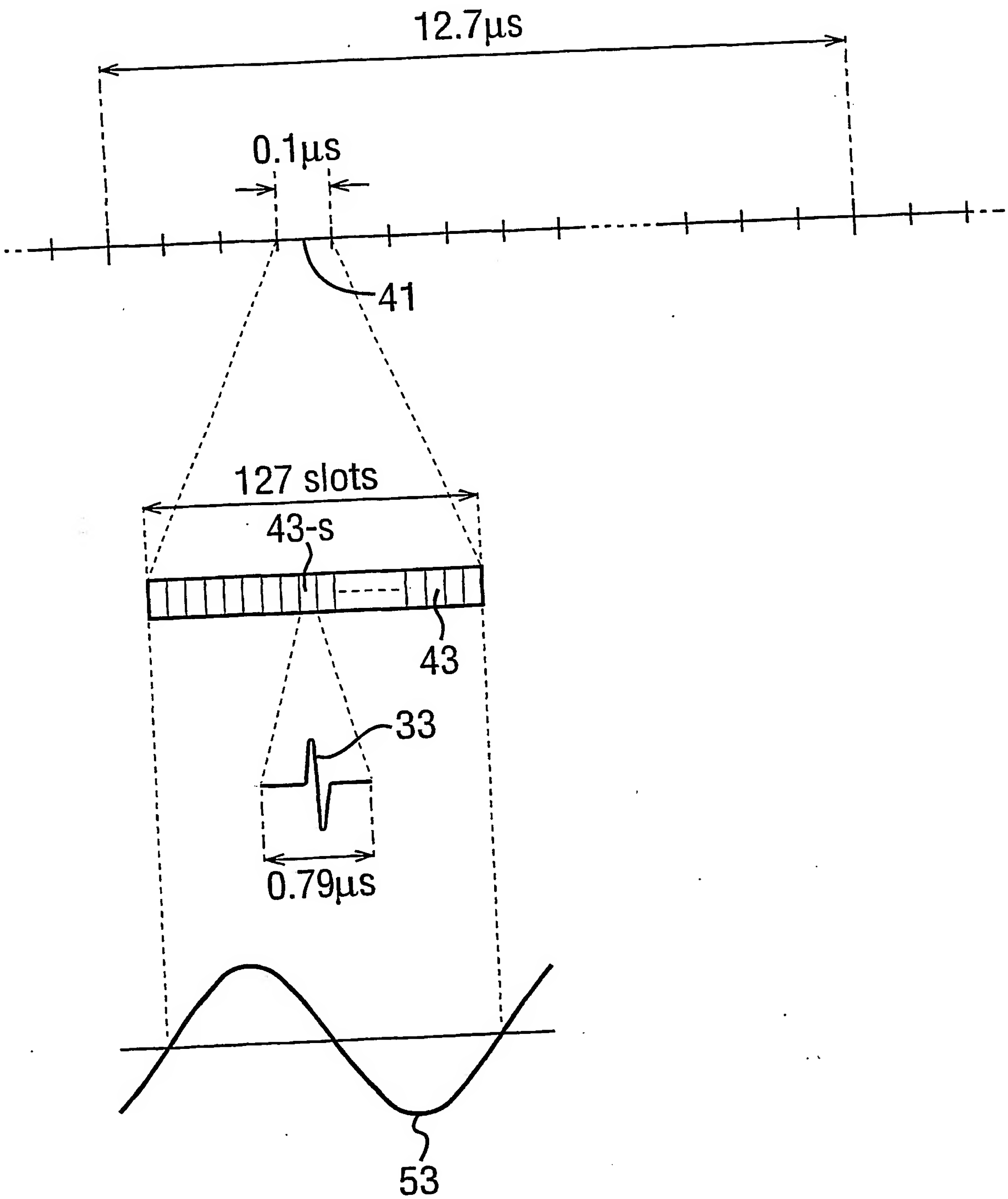


Fig. 4



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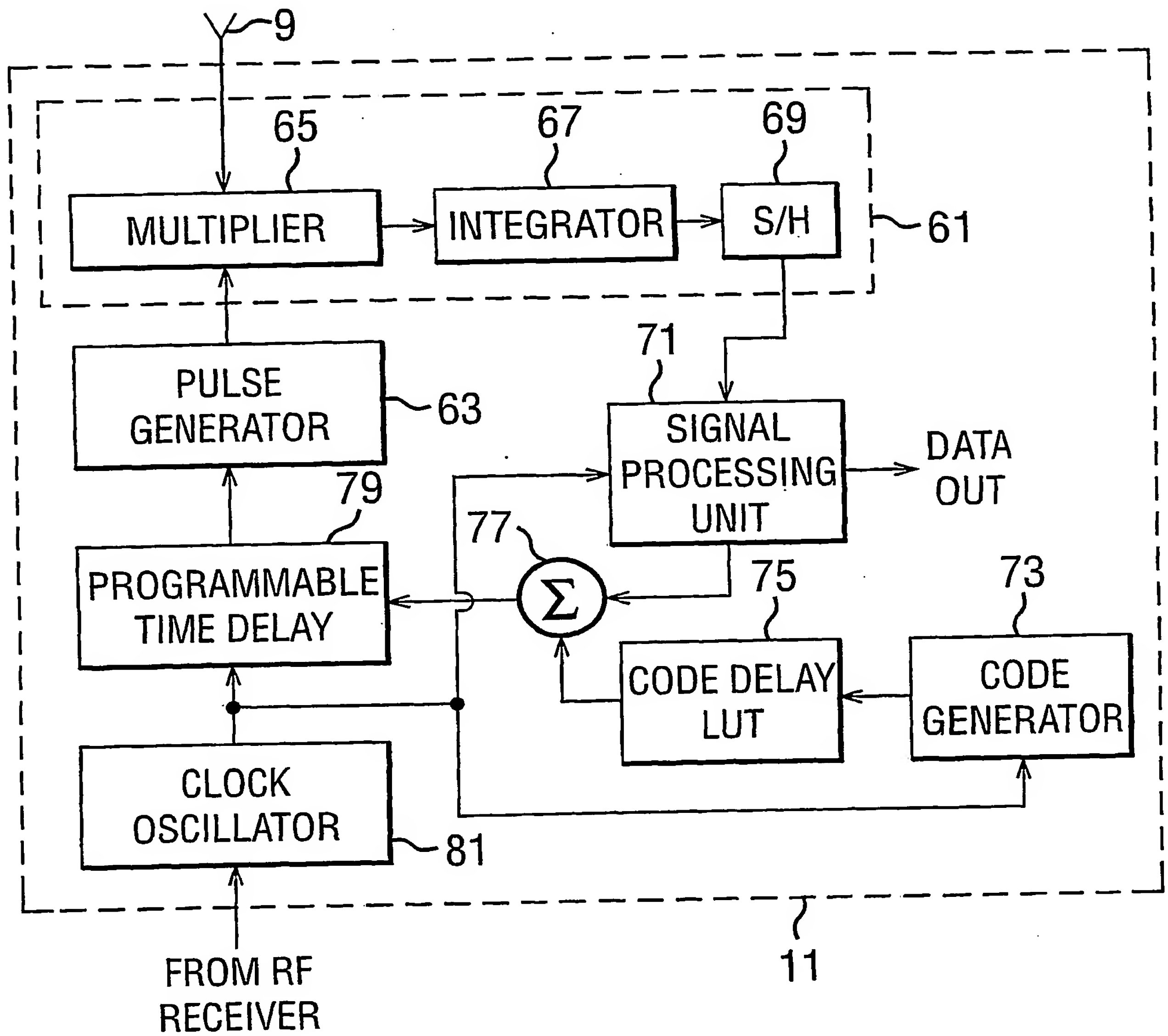
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MULTIPLIER
INTEGRATOR
S/H
61
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PULSE GENERATOR
63
SIGNAL PROCESSING UNIT
DATA OUT
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77
Σ
75
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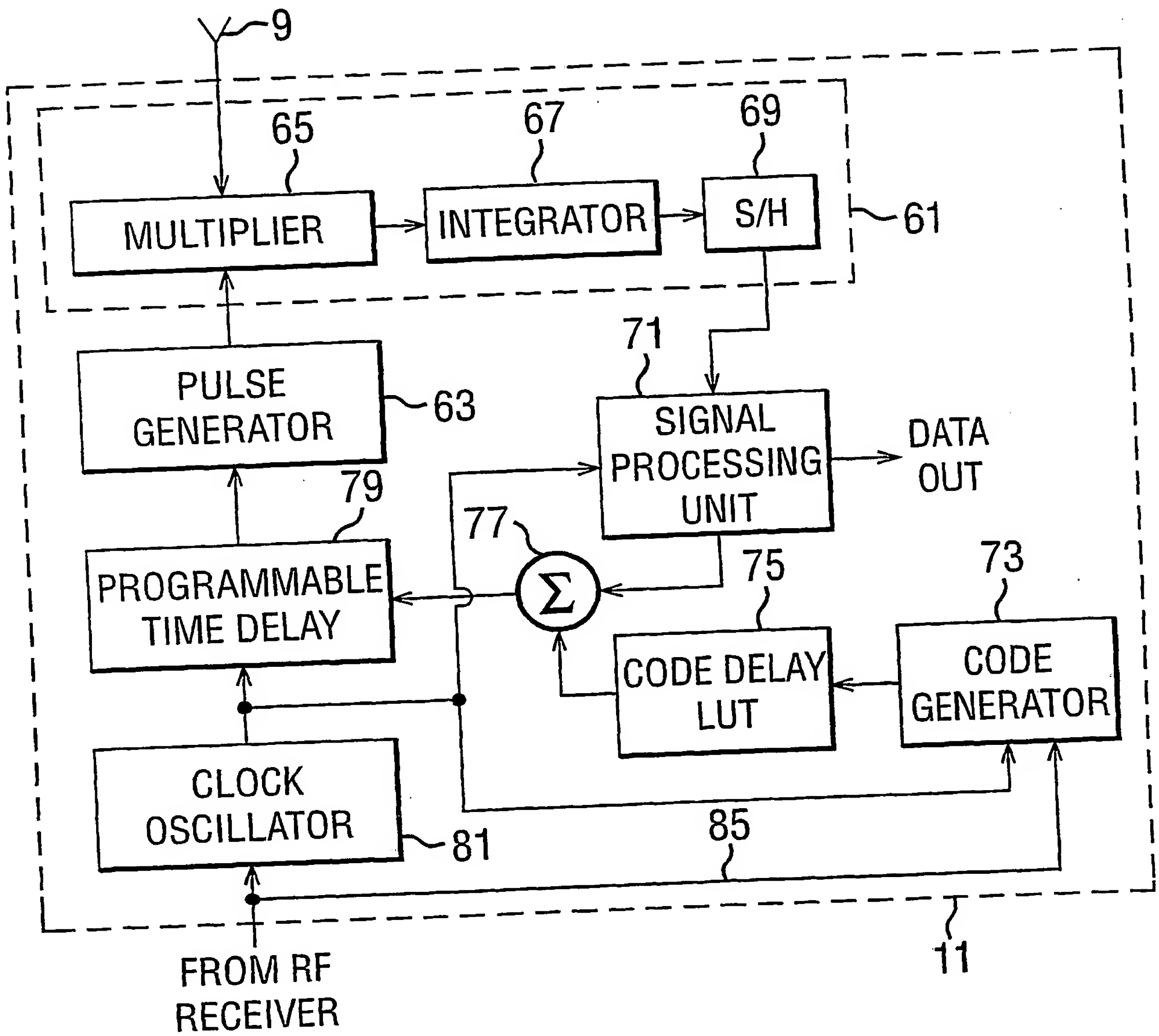
PROGRAMMABLE TIME DELAY
CODE DELAY LUT
CODE GENERATOR
CLOCK OSCILLATOR
81
11
FROM RF RECEIVER

Fig. 6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DATA OUT
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Σ
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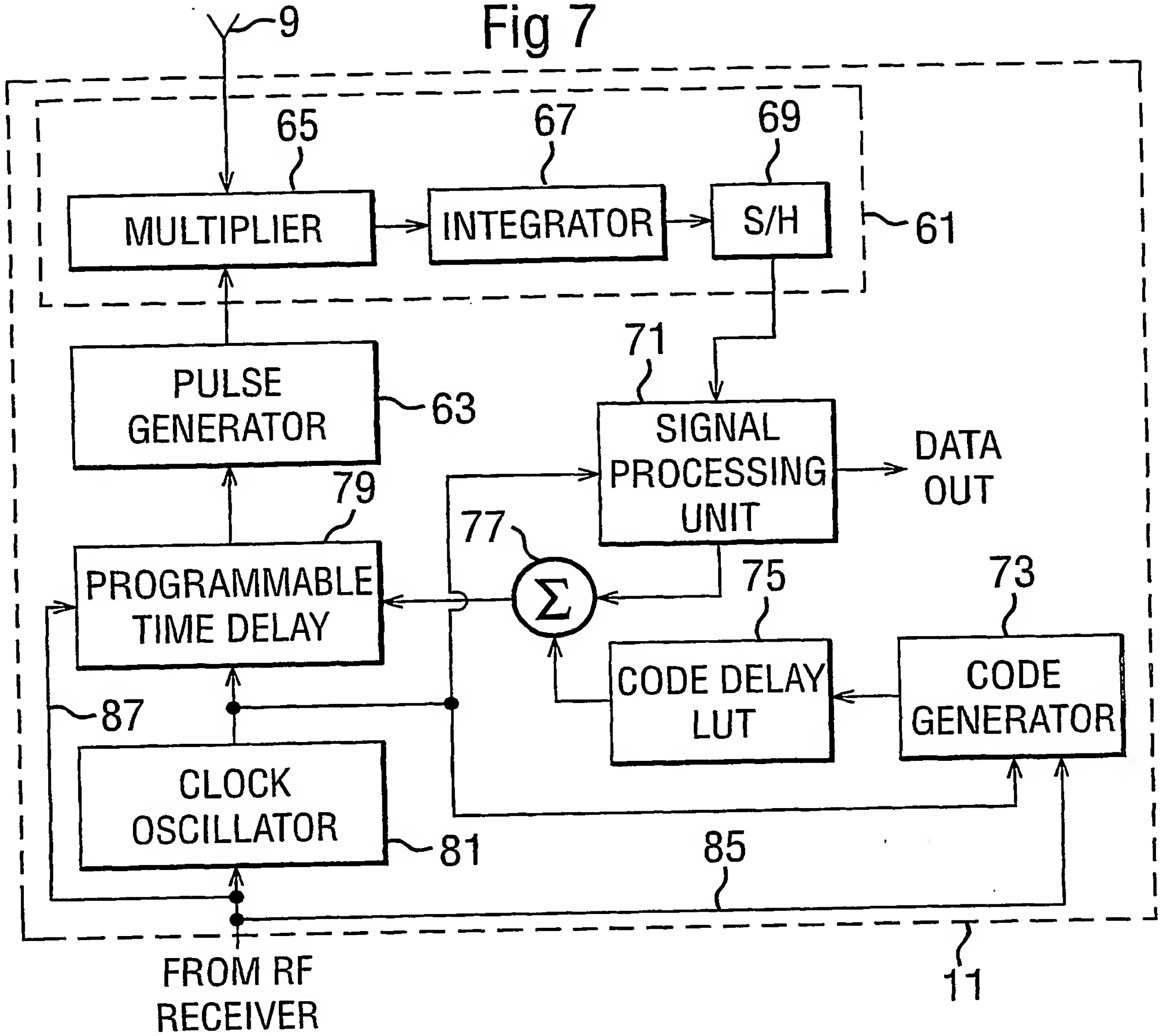
PROGRAMMABLE TIME DELAY
CODE DELAY LUT
CODE GENERATOR
CLOCK OSCILLATOR
81
85
11
FROM RF RECEIVER

Fig 7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S/H
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PULSE
GENERATOR
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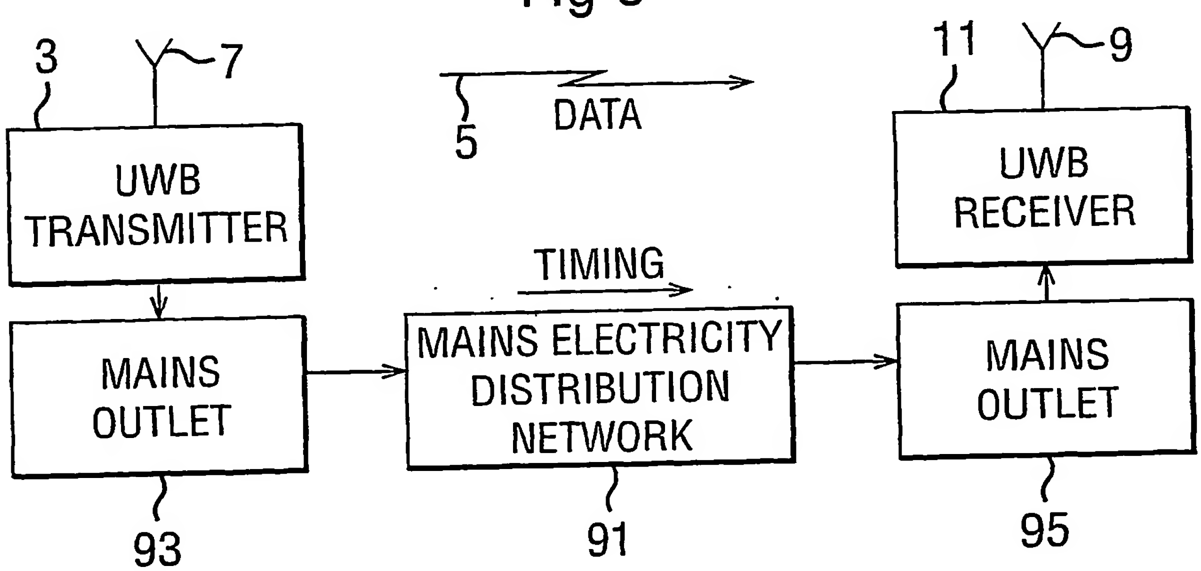
SIGNAL
PROCESSING
UNIT
DATA
OUT
79
77
75
73
PROGRAMMABLE
TIME DELAY
Σ
CODE DELAY
LUT
CODE
GENERATOR
87
CLOCK
OSCILLATOR
81
85
FROM RF
RECEIVER
11

Fig 8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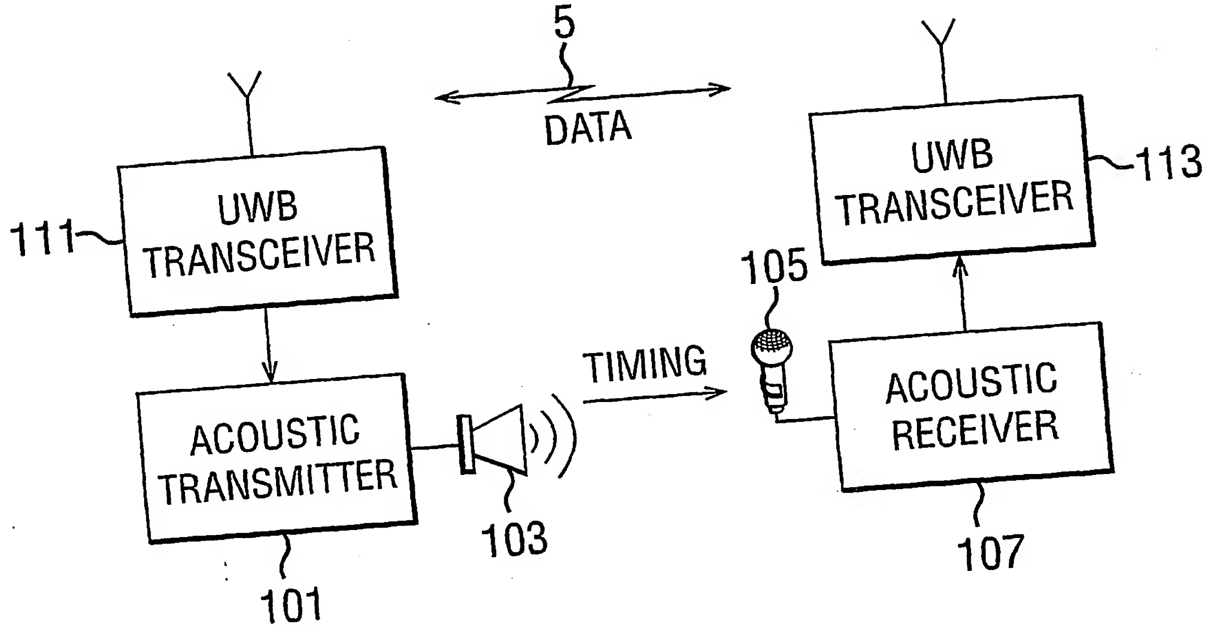
DATA
UWB
TRANSMITTER
UWB
RECEIVER
TIMING
MAINS
OUTLET
MAINS ELECTRICITY
DISTRIBUTION
NETWORK
MAINS
OUTLET
93
91
95

Fig 9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DATA
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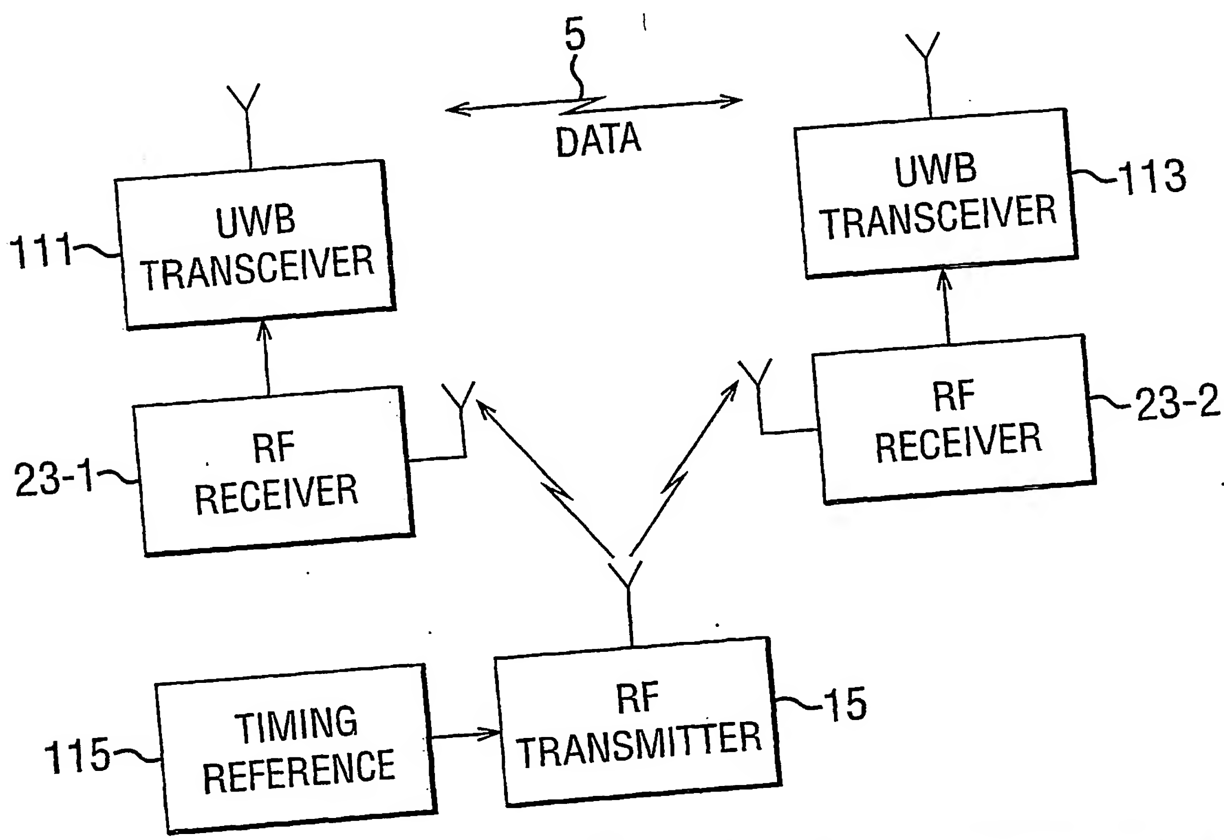
UWB TRANSCEIVER
113
105
TIMING
ACOUSTIC TRANSMITTER
ACOUSTIC RECEIVER
103
107
101

Fig 10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DATA
UWB TRANSCEIVER
111
UWB TRANSCEIVER
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RF RECEIVER
23-1
RF RECEIVER
23-2
TIMING REFERENCE
115
RF TRANSMITTER
15

INTERNATIONAL SEARCH REPORT

In ional Application No
PCT/GB 01/05733

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04B1/69

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04B H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 687 169 A (FULLERTON LARRY W) 11 November 1997 (1997-11-11)	1-3,5-7, 11,12, 14,15, 18,19
A	column 8, line 7 - line 17	4,8-10, 13,16, 17,20-30
	column 13, line 50 -column 14, line 60 column 16, line 8 - line 24; figures 17,18 ---	
A	US 6 054 950 A (FONTANA ROBERT J) 25 April 2000 (2000-04-25) abstract column 5, line 6 - line 29 column 7, line 17 - line 26 ---	1-30
	-/--	

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
8 April 2002	17/04/2002

Name and mailing address of the ISA	Authorized officer
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INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 01/05733

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6 097 974 A (CAMP JR WILLIAM O ET AL) 1 August 2000 (2000-08-01) column 3, line 36 - line 48 column 5, line 43 - line 50 column 6, line 54 - line 67	1-30

Form PCT/ISA/210 (continuation of second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/GB 01/05733

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			EP	1038361	A1	27-09-2000
			WO	9931812	A1	24-06-1999